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R.P. Marsden, B.A., M.B.K.S.

Research Department, Engineering Division
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R. P. Marsden, B.A., M.B.K.S

Summary

A recent CCIR Recommendation has established a digital coding standard for separate-component video signals in television studios. We may expect new digital studio equipment to conform to the CCIR standard. A satisfactory method of digital interconnection is now required to remove the need for analogue interfaces between such equipments.

The basic bit rate required for the video signal is 216 Mbit/s, and this requires considerably more bandwidth than existing composite analogue signals. Nevertheless, it is anticipated that a serial transmission format will be preferred to a parallel format over long distances because of the cost and size of multiway cable and connectors. Optical-fibre transmission is being studied because of its ability to carry wideband signals with very little equalisation for high frequency loss.

Prototype equipment to transmit a serial signal through an optical fibre has been built, and is described. The equipment takes in one CCIR signal in parallel form, recodes and serialises it for transmission, and reconverts it to parallel form in the receiver. The bit rate transmitted through the optical fibre itself is 270 Mbit/s.

This equipment has been successfully tested both in the laboratory and to send signals through an optical-fibre cable of length 800 m between two television studio centres. It is believed that this was the first time that CCIR-coded digital signals have been carried between studio centres by optical fibre.

The possibility of optical fibre transmission being widely used in studio centres is discussed. It is concluded that, despite the obvious advantages of optical fibres, there are drawbacks that must be overcome before this method of transmission is adopted. The present limits of optical switching technology, lack of standardisation, and the cost and complexity of a complete electro-optic interface are the main obstacles. However, there are encouraging signs that these problems will be overcome.

For a parallel connection format the bandwidth available from optical fibres would not be fully exploited, but a multiway cable could be made no larger than a co-axial video cable, with no crosstalk. Here too, standardisation of the cable and connector would be essential.

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OPTICAL FIBRE LINKS FOR DIGITAL YUV SIGNALS

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1. Introduction

1.1. The All Digital Studio Centre

The use of digital techniques for processing television signals is increasing rapidly. Many processes, particularly those that require the picture to be stored, would be impractical if they were restricted to analogue signals. The first generation of digital video equipment has, however, retained analogue inputs and outputs because it must fit into an existing programme chain.

As the proportion of digital equipment rises, it will become worthwhile to convert large parts of the chain to digital operation even though some of the individual processes do not warrant it. Most equipment will no longer need analogue-to-digital interfaces, and some of the limitations on quality imposed by analogue systems will be removed. The recent CCIR Recommendation[1] has established a coding standard for YUV component signals which should make it possible to ensure that future digital equipments are compatible. This Recommendation will apply irrespective of the broadcast standard (PAL, SECAM, NTSC) used, and has a margin of quality to allow for losses in such processes as picture expansion and Chroma-key.

1.2. Optical Fibre Interconnections

With the interconnecting signals quantised to 8-bit accuracy, the basic bit rate for a component-coded video signal is 216 Mbit/s. This requires a bandwidth of more than 100 MHz, considerably higher than the 6 MHz required for an analogue signal. Nevertheless, it is anticipated that serial transmission will be preferred to parallel over long distances because of the cost and size of multiway cable and connectors. Optical fibre transmission of the serial signal is being studied because little or no equalisation is required at these higher frequencies, even over the longest runs to be found in a studio centre. There are also other advantages. The cable need contain no metallic elements and does not suffer from and cannot cause interference to other cables, optical or electrical. An optical cable the size of a conventional video cable can contain several fibres, each carrying a separate video signal. (A multi-fibre cable could even be a compact way of carrying the signals in parallel form.)

Current experimental work is centred on a link representative of the longest that can be expected within a studio centre. One YUV signal is carried by a single-core optical cable and means are provided at each end of the link for converting between serial and parallel form.

2. The Experimental Equipment

2.1. Choice of Optical Components

Much of the impetus for high-frequency optical fibre transmission comes from the telecommunications industry. The national telecommunications organisations need the wide bandwidths of optical fibres to offer the range of services that their customers are now demanding. They are also keen to eliminate intermediate repeaters on all routes because of the cost and inconvenience of installing, housing, powering and maintaining them. The type of components that are commercially available are, therefore, those that will maximise both distance and bandwidth.

The digital YUV video bit-rate is nearly twice the standard trunk rate of 140 Mbit/s, but the links within studio centres will be considerably shorter. This has led to some difficulties in obtaining suitable components; available components are generally designed with the trunk network in mind.

It was decided to build equipment capable of transmitting one CCIR-coded digital video signal through 1 km of fibre. This distance was chosen as being representative of the longest that could be expected in a studio centre. The bandwidth of the signal can be estimated from the CCIR Recommendation. The sampling rates are 13.5 MHz for the luminance signal and 6.75 MHz for each of the two colour difference signals. Assuming 8-bit quantisation of each signal this leads to a total serial bit rate of 216 Mbit/s. Making an allowance for transmission coding, which may include signalling and error protection, we arrive at a bit rate in the range 250–300 Mbit/s.

Light sources for optical fibre links are either light-emitting diodes or laser diodes. Both types of device are highly non-linear and are best suited to a two-level transmission code. With a binary code

the highest fundamental frequency on the link is half the data rate, i.e. 125–150 MHz.

For these frequencies, on a 1 km link, graded-index multi-mode fibre is the obvious choice. Mono-mode fibre would not be significantly better and step-index fibre would be too dispersive. The loss through dispersion on graded-index fibre at 125–150 MHz is between 1.4 and 1.9 dB/km. (This assumes a fibre with a specified minimum 3 dB product of 200 MHz.km.) This is in addition to the loss from scattering and absorption, which is an optical power loss and is almost independent of frequency.

It was decided to use 820 nm transmission, because of the wider range of components available and their lower cost. However, the possibility of 1.3 μm transmission was considered even though it is not necessary for a short link. Most experimental work is now directed towards 1.3 μm and even 1.55 μm transmission because of the greater distances these wavelengths allow. It seems reasonable to assume that these are the wavelengths for which components will become most readily available. In particular, almost all integrated optical development (see Section 3) is centred on the longer wavelengths. So any components which could be used at both 820 nm and 1.3 μm were to be preferred.

The optical receiver is a p.i.n. photo-diode integrated with a thick-film hybrid pre-amplifier and is available as a commercial module. A p.i.n. diode has an intrinsic semiconductor region between the p-type and n-type regions that make up a normal junction diode. The intrinsic region increases the efficiency of the diode and reduces its response time. The integrated pre-amplifier has especially low input capacitance to counteract the diode's high impedance.

An avalanche photodiode could have been used instead, but the p.i.n. diode module was chosen for two reasons. A p.i.n. diode can be run from a low voltage supply, in this instance 15V, whereas an avalanche photodiode requires about 200V. This is inconvenient to provide, particularly if it is intended to produce a compact design. Secondly, most avalanche photodiodes with the required frequency response are made from silicon. This material can only be used at wavelengths shorter than about 1.1 μm. On the other hand, the p.i.n. diode, being made from gallium-indium arsenide, responds to radiation at 820 nm or 1.3 μm.

With the choice of receiver settled, a power budget was drawn up to determine the requirements for the transmitter. In practice the choice was very limited because of the high modulating frequency. The fastest commercially available light-emitting diode known was capable of modulation at only up to 70 MHz, and it was almost certain that a laser diode would have to be used regardless of the actual power requirement.

The details of this power budget were as follows:

Receiver derating for use at 820 nm instead of 1.3 μm	3.0 dB
Cable loss (absorption and scattering)	6.0 dB
Connector loss (4 butt connectors at 4 dB)	16.0 dB
Modal dispersion loss (at maximum fundamental frequency)	1.9 dB
Total losses	26.9 dB
Receiver's sensitivity at 270 Mbit/s and 1.3 μm (for a bit-error rate of 1 in 10^9)	−33.0 dBm
Minimum power to be coupled into fibre at transmitter	−6.1 dBm

Thus, the transmitter power would have to be at least −6.1 dBm, or about 250 μW. This is comparable to the maximum power that would have been obtained from a light emitting diode. It was decided, in using a laser diode, to leave a margin for ageing and tolerances. The margin would also allow the receiver and transmitter to be used for experiments with splitters and switches.

The laser that was chosen has a specified minimum output power into its fibre tail of 3 mW (+4.8 dBm) at 820nm. The system margin is therefore 10.9 db.

The transmission path loss allows for four butt connections in the link. These are the simplest type of optical fibre connection. The plane ends of the fibre are brought together inside some kind of precision guide that ensures they are accurately aligned. (Any lateral misalignment causes loss.) A new connection should have a loss of no more than about 2 dB. However, with frequent disconnection and reconnection this can rise through damage to the fibre end-faces and build-up of dirt. When the loss reaches about 5 dB it is expected that the connectors would be replaced, so a representative figure of 4 dB per connection was used.

2.2. Coding for Transmission

The serialised bit-stream is carried by using it to amplitude modulate the light output from the laser. The modulation is close to 100%. However, before the pcm video data can be carried it must be recoded to include clock timing information; i.e. a sufficient number of "one" to "zero" and "zero" to "one" transitions must be included at all times to allow the pulse retiming circuits in the receiver to operate correctly. The code must also minimise the low frequency content of the transmitted bit stream. This is because it is difficult to produce a link which maintains d.c. levels. In this instance it is particularly important that the low frequency content should be small because the receiver effectively integrates the incoming signal. Any prolonged excess of "ones" over "zeroes" or vice versa will thus cause it to saturate.

Data scrambling, which does not increase the bit rate, was rejected. Because there is no increase in the bit rate all combinations of "ones" and "zeroes" are still possible, just as they were in the original signal. Although a local preponderance of one digit over the other is less likely in the scrambled signal, an even distribution cannot be guaranteed. Nor can an upper bound be placed on the number of successive "ones" or "zeroes" transmitted, from which to specify the dynamic range of the receiver and the performance of the clock recovery circuits.

Codes requiring the transmission of three or more levels were also eliminated because of the difficulty of applying multi-level modulation to a laser. This rules out transmission codes such as AMI and HDB-3.

The first binary code considered was CMI (coded mark inversion). This is very simple to produce, has frequent transitions between "one" and "zero" to operate the pulse retiming circuits and has no d.c. component. However, CMI puts two binary digits in place of every one in the original signal, requiring the operating frequency of the entire link to be doubled. This was felt to be excessive. There are other codes, almost as simple, which would be adequate and which would increase the bit rate by a much smaller factor.

One such code is 5B6B. Every five bits of the original signal are translated into six bits for transmission. This code satisfies all the requirements; the longest run of similar symbols is six, and the low frequency content is only slightly higher than CMI. However, because 5B6B requires the original signal to be divided into blocks of five bits it does not fit easily within the eight-bit structure of the video signals.

It was therefore decided instead to use a 16B20B code that was developed at the BBC Research Department for digital video-tape recording.[2] This results in a bit rate of 270 Mbit/s. Every 20 bit word used in the code has ten "ones" and ten "zeroes", so there is no d.c. content, and the longest run of successive "ones" or "zeroes" is five. There are fifty spare code words and one of these is used to indicate word boundaries by substituting it for a video word at the same point in every line blanking interval.

The bit-error rate on optical fibre links installed in studios is expected to be 1 in 10^9 or better, corresponding to about one error every four seconds. As the visibility of errors at this rate on pcm signals is low, error protection is not included in the experimental equipment. However, the 16B20B decoder could be made to detect single bit errors because they cause "digital sum" violations in the affected codewords. Errors could then be concealed, for example by repeating the previous pcm sample. It is not possible to correct errors, however, because there is insufficient information in the code to discover exactly which binary digit within a word has been affected.

No provision is made on this experimental link for a separate signalling channel. The video data already contains information about line numbers in the line blanking interval, and this will be carried on the link together with the normal video samples. Because the blanking waveform is completely predictable it could be replaced as required by signalling or sound samples, and then be reconstituted in the receiver. The total capacity that can be made available in this way should be sufficient for all envisaged requirements.

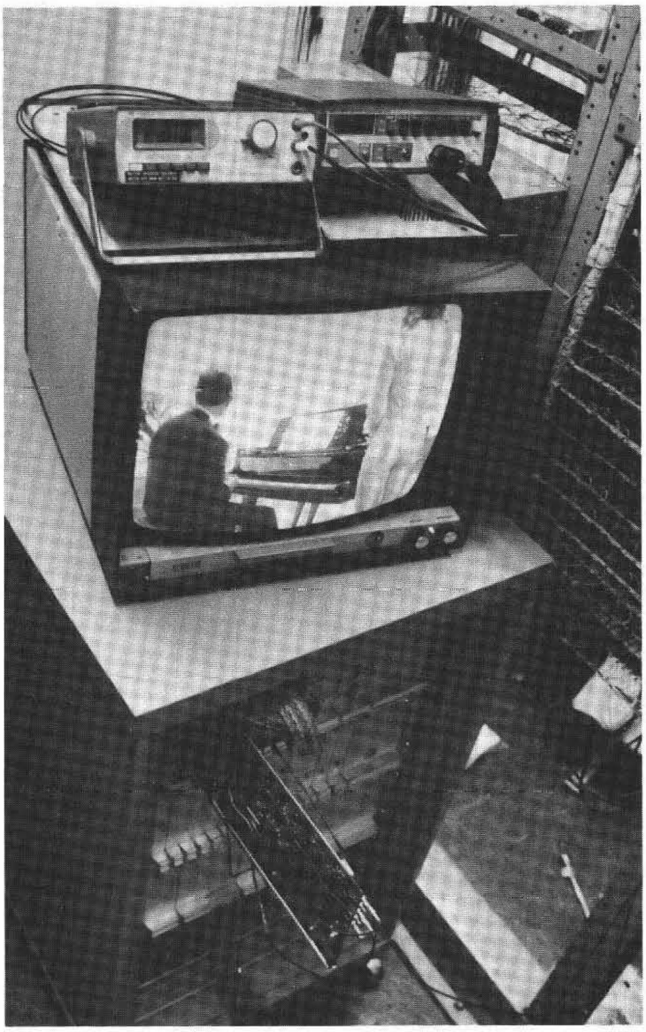
The broadcasters are presently formulating a proposed interface specification and it is expected that the experimental link will be capable of working with it.

2.3. Preliminary Results

The equipment was successfully tested through 1 km of optical fibre in the laboratory. The excess loss at 135 MHz was 0.5 dB, implying a bandwidth-distance product for the fibre of almost 400 MHz.km. It was therefore not necessary to equalise for high-frequency losses in the optical fibre.

The equipment has also been used to demonstrate the digital transmission of high quality YUV

signals between two studio centres by optical fibre. The optical fibre cable used for the purpose was installed in existing ducts by British Telecom. It is 800 m long and contains eight fibres, one of which was used for the experiment. The power launched into the fibre cable was -2.3 dBm, and the power received varied between -18.4 dBm and -20.2 dBm. The cause of the high loss was a badly degraded connector at one end of the cable. Nevertheless the received power was adequate for completely satisfactory pictures to be received.



The receiving terminal during the studio centres test

3. Long-term Prospects for the Use of Optical Fibres in Studios

The main advantage of optical fibres over co-axial cables is their wide bandwidth. An optical fibre 1 km long will usually need no equalisation at 125 MHz (if it is a graded-index fibre). A conventional co-axial cable would require about 125 dB, if that were possible. Other advantages of optical fibres include electrical isolation and immunity to interference. An optical cable is small and light in weight, making it easy to install. If necessary many fibres can be incorporated into one cable; an eight-fibre cable need be no larger than a normal video co-axial cable, and there will be no crosstalk.

However, before a commitment is made to optical fibres there are several drawbacks that must be considered. The electro-optic interfaces that must be provided at both ends of the fibre are expensive and consume space and power. There is very little standardisation of optical fibre components, except for the fibre itself. The design of a compact connector that will withstand frequent connection and disconnection is still causing problems. Switching technology is as yet at an early stage of development, and there is no means of amplifying a small optical signal for distribution to a large number of destinations; both of these operations may require the signal to be returned to the electrical domain.

All of these problems will need to be solved if optical fibre transmission is to be accepted as the replacement for copper cables. The signs are that most of them will be. Considerable research and development is being carried out into all aspects of optical fibre transmission, mainly by the telecommunications industry. The large orders that will be placed over the next few years should allow the investment costs to be recovered and thus reduce prices. The broadcasters should benefit from these developments, much as they have benefited from the integrated circuits developed for the space and computer industries.

Standardisation is taken very seriously but there are several obstacles in its path. The technology is still developing, making it difficult to define standards that are not restrictive or soon outdated. Standards must inevitably be the subject of international discussion, and this takes time. A number of de-facto standards have emerged, particularly for connectors. None of these is fully satisfactory, but they are sufficiently well established that it would take an exceptionally good design to dislodge them.

Switching and amplification belong to what is now being called "integrated optics". Electro-optic components such as optical directional couplers, modulators and switches are made by diffusion or deposition on small substrates. The technology is similar to that of integrated circuits, but the materials are different and the patterns are at

present simpler and larger, with features of the order of several millimetres.

Integrated optics has rapidly become a subject in its own right, and progress to date is encouraging. Although few integrated optical devices are likely to be in production in time for the first generation of digital broadcast equipment they may well form the basis of the second generation.

Hybrid integration allows opto-electronic devices and purely electronic devices to be combined on a single substrate. This technique is used, for example, in the p.i.n. photodiode receiver module being used in the experimental link. If an entire transmitter or receiver, from parallel digital video data to serial optical bit stream, could be put into two or three small packages, the future of optical fibre links for digital studio interconnections would be very good indeed. Optical interfaces could be fitted as standard to every piece of digital equipment, and electrical outputs dispensed with entirely.

Alternatively, if a parallel format were preferred, the receiver and transmitter would be simpler but they would have at least eight optical inputs and outputs. A connector for eight fibres would then be required, and standardisation for such a complex component would be essential to make a parallel optical interface viable. However, an eight-fibre cable would be no larger than an ordinary video co-axial cable, and there would be no crosstalk between the fibres.

4. Conclusions

A recent CCIR Recommendation has established a digital coding standard for separate-component video signals in television studios. The basic serial bit-rate for the video signal is 216 Mbit/s, and an optical fibre link would be able to carry such a signal in serial form with very little high frequency loss.

A prototype optical serial link equipment has been built and tested with 1 km of optical fibre in the laboratory and an 800 m optical fibre cable installed between two studio centres. The equipment takes a component-coded video signal in parallel form, and recodes it and serialises it for transmission at a bit rate of 270 Mbit/s. The receiver performs the inverse process.

Despite the obvious advantages of optical fibres, there are drawbacks that must be overcome before this method of transmission will be widely accepted in studio centres. The present limits of optical switching technology, lack of standardisation, cost and complexity of a complete electro-optic interface are the main obstacles. However, there are encouraging signs that these problems can be overcome.

For parallel connections the bandwidth available from optical fibres would not be fully exploited, but a multiway cable could be made no larger than a co-axial video cable, with no crosstalk. Here too, standardisation of the cable and connector would be essential.

5. References

1. CCIR Recommendation 601.

2. PARKER, M.A. *and* BELLIS, F.A., 1982. "Signal processing for an experimental 216 Mbit/s video recorder". Proc. IERE Conf. on video and data recording, Southampton, 1982.

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